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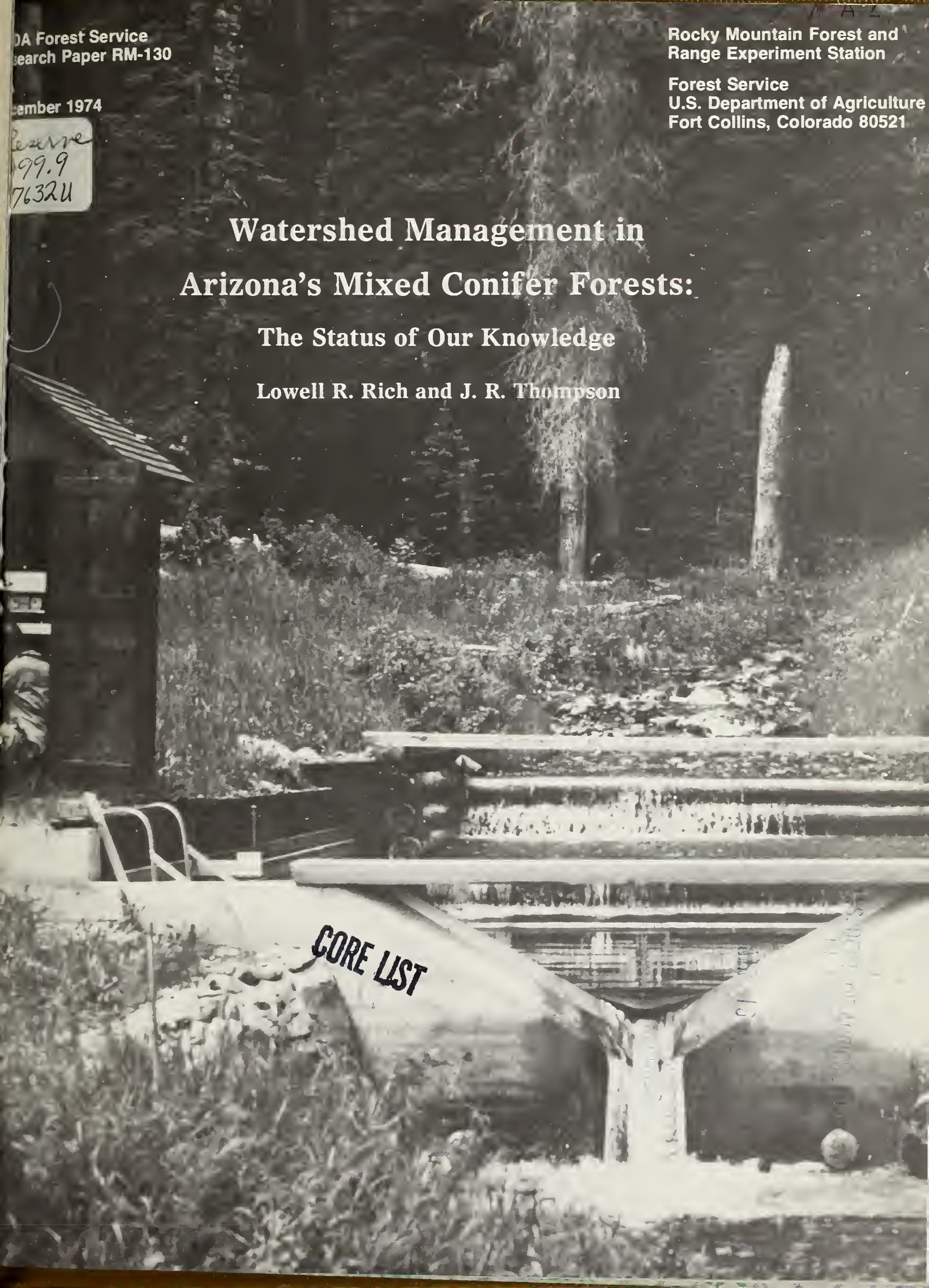
Watershed Management in Arizona's Mixed Conifer Forests:

The Status of Our Knowledge

Lowell R. Rich and J. R. Thompson



Abstract

Removing mixed conifer forest vegetation has increased water yields approximately in proportion to the percent of the area in cleared openings. Most of the yield increase can be accounted for by the reduction in evapotranspiration. Reduced soil-moisture deficit and increased snow accumulation and melt rates in the cut openings contribute to these increases. When fitted to the timber-stand structure, patchcutting is (1) compatible with recommended mixed conifer silviculture, (2) beneficial to wildlife, and (3) esthetically pleasing. Although mixed conifer areas make up only 0.4 percent of the total land area of Arizona, they contribute 6 percent of the State's water yield. Intensive management of these forest lands could increase annual streamflow 36,500 acre-feet per year—roughly 12 billion gallons of water per year.

Keywords: Water yield improvement, mixed conifer, sediment yield.

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Watershed Management in Arizona's Mixed Conifer Forests: The Status of Our Knowledge

by

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Watershed Management in Arizona's Mixed Conifer Forests: The Status of Our Knowledge

Lowell R. Rich and J. R. Thompson

Introduction

All available evidence still supports the hypothesis that, "... modification of the various vegetation types, is ... promising for increasing the water supply ..." (Barr 1956). Throughout the Rocky Mountains, the mixed conifer type has often been emphasized in water-yield improvement research because the potential for increase appeared greatest there.

Watershed management research in Arizona dates from the formal establishment of the Sierra Ancha experimental watersheds on the Tonto National Forest in 1932. Although water yield has often received primary emphasis, forage, timber, and other resources have always been considered as important and integral parts of the total watershed ecosystem. This Paper summarizes the results of water yield studies that apply to Arizona's mixed conifer vegetation association, and hopefully provides a foundation from which alternative forest management practices can be more easily evaluated.

Description of the Area

The high water-yielding areas of the Southwest are those with major water surpluses as a result of precipitation exceeding evapotranspiration (Fletcher and Rich 1955). This delineation coincides closely with the mixed conifer and aspen forests. Sometimes referred to as the pine-fir, spruce-fir, and Douglas-fir types, the mixed conifer includes those timber stands above approximately 7,000 ft, where ponderosa pine makes up about 60 percent or less of the total volume. It is a highly diversified type (fig. 1), including a wide mixture of: Engelmann spruce (*Picea engelmannii* Parry); blue spruce (*Picea pungens* Engelm.); Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco); white fir (*Abies concolor* (Gord. & Glend.) Lindl.); corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.); ponderosa pine (*Pinus ponderosa* Laws.); southwestern white pine (*Pinus strobiformis* Engelm.); quaking aspen (*Populus tremuloides* Michx.); Arizona alder (*Alnus oblongifolia* Torr.), bigtooth maple (*Acer grandidentatum* Nutt.); Arizona walnut (*Juglans major* (Torr.) Heller); New-Mexican locust (*Robinia neomexicana* A. Gray); and Gambel oak (*Quercus gambelii* Nutt.).

There are approximately 240,000 acres of mixed conifer in Arizona (Spencer 1966). Although aspen is often an associate species, it also occurs in pure stands as a climax (or fire climax) species. For this paper, we consider Arizona's 79,000 acres (Spencer 1966) of aspen as a part of the mixed conifer type, making a total of 319,000 acres. Although the mixed conifer and aspen cover only 0.4 percent of the State's area, they produce more than 6 percent of the State's surface water, greater than 10 times their proportionate share.

Only a small part of the total precipitation that falls on Southwestern watersheds is recovered as streamflow. Of an estimated 83 million acre-ft of annual precipitation in Arizona, 76.7 million are lost to evapotranspiration alone (Kelso et al. 1973). Channel losses, ground water, and other factors account for an additional 3.4 million acre-ft. Research has shown that vegetation manipulations can increase water yields by decreasing evapotranspiration.

The ever increasing demands on wildlands by an expanding population is particularly noticeable in the mixed conifer, with its associated meadows and aspen stands. Not only is the timber of high value, and water a prime concern because of its quality and quantity, but also the esthetics and wildlife are important to the recreationist or transient tourist. The cool summer climate makes the area highly attractive for summer homes.

Figure 1.—The mixed conifer type is a highly diversified mix of eight principal tree species, interspersed with grassy meadows.

The mixed conifer is a prime habitat for such species as elk, deer, bear, turkey, grouse, squirrel, and numerous songbirds. Trout fishing is almost totally dependent on the cool, clear waters that come from the lands of this vegetation type. Forage production in the parks and open meadows is higher than in most other areas of the Southwest, making them valuable summer range for livestock.

In general, the mixed conifer stands in Arizona occur where the annual precipitation averages more than 30 inches. Summer (May-

September) and winter (October-April) precipitation are almost equal, but 75 percent or more (often as high as 90 percent) of the streamflow comes from winter snowfall. Soils are predominantly basalt-derived Sponseller, with medium to moderately fine texture, and porous. Soil depth varies over a wide range, but in general could be classified as moderately deep.[2]

Research Background

Many factors—such as precipitation, interception, evaporation, transpiration, cloud seeding, cover characteristics, and channel conditions—influence water yields. Vegetation exerts a strong influence on many of these factors, and because vegetation is amenable to management by man, man's actions can have a pronounced influence on water yield.

Early Concepts

Many early observers could see the tenacious bond between forests and water. Zon (1912) stated that "Accurate observations . . . establish with certainty the following facts in regard to the influence of forests upon climate; . . . Forests increase both the abundance and frequency of local precipitation over the areas they occupy . . . ." It was theorized that forests caused greater precipitation and therefore spawned the springs and rivers that always had their origin in forest and associated wildlands. Concern was registered by some over the extensive clearing of trees in the Midwest during the 19th century. The fear was not that the forests were being depleted, but that large-scale removal of the forests could diminish precipitation in the area.

Eighteen years ago, Barr (1956) recommended that 3,025,000 acres within the Salt-Verde basin in Arizona be treated for the production of water. Proposed treatments on selected areas included: drastic thinning in pine; removal of Douglas-fir, white fir, and 50 percent of the pine along mountain streambanks; replacement of lowland riparian woody species (phreatophytes) with herbaceous cover; and conversion of pinyon-juniper stands to grass. These, along with other treatments in the proposed action program, were predicted to be capable of increasing streamflow by 285,000 acre-ft per year.

[2]*Leven, Andrew A., and Peter J. Stender. Hydrologic survey and analysis, Black River barometer watershed, Apache National Forest. (Office Rep.) 1967.*

Research results have not supported these optimistic predictions. Pinyon-juniper conversions on Beaver Creek have not affected water yield (Brown 1970). Thinning treatments in pine on Beaver Creek and mixed conifer on Workman Creek, and removal of riparian vegetation on the North Fork of Workman Creek, likewise have not measurably increased streamflow (Brown 1970, Rich et al. 1961). Although clearing woody phreatophytes has increased streamflow (Horton and Campbell 1974), the portion of this increase lost to replacement herbaceous vegetation is still unknown.

Paired Watershed Experiments

The Swiss, in 1900, were the first to gage a pair of small watersheds to determine the influence of forests on streamflow—one watershed was 98 percent in forest, the other only 30 percent. They concluded that the forest acted to equalize flow through dry and wet periods of the year without diminishing the total yield (Zon 1912). Critics pointed out that there were differences in the two basins besides vegetation differences; therefore, the conclusions were suspect.

The calibrated watershed approach began at Wagon Wheel Gap, Colorado, in 1910. By relating the flow of two similar catchments over a period of years, and then altering the vegetation on one without disturbing the other, subsequent changes in the flow relationship could be attributed to the "treatment." Bates and Henry published their final report on Wagon Wheel Gap in 1928, the first scientific contradiction to the earlier held views of forests and water yield. The new technique spread like wildfire, and scores of paired watersheds were established. Almost invariably these experiments showed that removal of significant amounts of forest vegetation increased water yields (Goodell 1958; Hornbeck et al. 1970; Hoover 1944; Hoyt and Troxell 1934; Johnson and Kovner 1956; Lewis 1968; Love 1955; Martinelli 1964; McGuinness and Harold 1971; Patric and Reinhart 1971; Rich et al. 1961; Rich 1972; and Rothacher 1965, 1970).

Hibbert (1966) in summarizing results from 39 such studies, concluded that, ". . . forest reduction increases water yield, and reforestation decreases water yield." But he went on to say that wide variations among individual treatment results made predictability uncertain. Because conclusions drawn from paired watershed studies included such qualifying statements as "similar effects may not neces-

sarily hold for different climatic, soil, and vegetative conditions," proponents of the approach were forced to return to basic hydrologic studies to explain and use their results.

Plot Studies

Decreased snow interception losses following forest cutting was once believed to be a major cause of increased streamflow. Hoover and Leaf (1966) found, however, that mechanical removal and transport of intercepted snow was more important than vaporization in lodgepole pine and Engelmann spruce in Colorado. In ponderosa pine in Arizona, Tennyson (1973) concluded that "Most of the intercepted snow reached the snowpack on the gound, representing no significant loss to the water budget on site."

Reduced evapotranspiration seems to be the principal reason for increased water yield when forest openings are created. Kovner (1956) showed that the increase in streamflow after removing all forest vegetation on an oak-hickory watershed, "... was due to a corresponding decrease in the amount of evapotranspiration." Data from the Fraser Experimental Forest indicate that decreased evapotranspiration losses in cut strips in lodgepole pine and Engelmann spruce, along with redistribution of the snowpack, are the main factors explaining increased water yield (Hoover and Leaf 1966).

In Southwest mixed conifer forests, regrowth of trees in clearings cut for water yield improvement may not adversely affect the yield increase for some time. This conclusion is based on several factors, the combination of which is unique to this area: (1) snowmelt is the primary source of streamflow, (2) summer rains are normally adequate to satisfy evapotranspiration requirements during the growing season, (3) the supply of solar energy is high, and any changes in the surface albedo are therefore more pronounced in affecting the net energy level, and (4) soils are porous, allowing rapid infiltration and drainage.

Shading is, undoubtedly, the key element affecting water yield increases from forest patchcutting. It is responsible for reducing evapotranspiration in the opening by decreasing radiant energy. Shading also can effectively reduce the size of root systems (Kramer 1969). Depth and extent of the roots obviously affect water use.

Water use studies that compare tree species with brush or grass, consistently show less evapotranspiration for the replacement vegetation. Table 1 summarizes some of these studies that apply to the mixed conifer type.

Research in Arizona

The following paragraphs summarize and interpret the basic treatments and most significant results obtained from the three Workman Creek watersheds, which were instrumented in 1938, and the Castle Creek and Willow-Thomas Creek watersheds, which were installed in 1956 and 1963, respectively. Physical and vegetation characteristics of these watersheds are described in the appendix, along with more detailed descriptions of the treatments applied and results obtained.

The experimental paired watersheds were established to serve as models to produce data applicable to larger areas. Threshold or extreme values were considered the primary need. First treatments applied to the Workman Creek watersheds were to determine the maximum water yields obtainable on one watershed, and to test the effects of practical timber harvest operations on water and sediment yields on another.

Intermediate forest removals were studied at Castle Creek and Willow Creek. Castle Creek watersheds were set up to develop a system of timber management that would improve both water and timber yields and maintain other watershed products. Willow Creek was a second test of the effects of a practical type of timber management on water and sediment yields. The treatment, completed in September 1972, was silviculturally fitted to the existing forest stand of the 490-acre East Fork watershed. Water yield results from Willow Creek will be available in 4 or 5 years.

The Thomas Creek watersheds, another calibrated pair in the mixed conifer, are the last calibrated and untreated watersheds in the White Mountains. For this reason it is planned to gain as much information as possible on multiproduct evaluation of resource management practices from these watersheds. The following are the overall objectives:

1. Validate, refine, and pilot-test resource response models for planning management of mixed conifer stands in the Southwest.

2. Determine and evaluate effects of selected resource management practices on landscape esthetics and other environmental and recreational values.

3. Determine cost, production rates, and environmental consequences of cable logging in mixed conifer forests on steep slopes.

Table 1.--Comparison of average daily evapotranspiration rates for some mixed conifer species, brush, and grass, in different localities

Cover type	Location	Season	Evapotranspiration	Reference
			Inches/day	
Spruce	Alberta	July	0.185	Storr et al. 1970
Spruce	Colorado	July-October	.132	Brown and Thompson 1965
Spruce	Europe	Unknown	.169	Rutter 1968
Fir:	Sweden			
Dry site		May and June	.134	Rutter 1968
Wet site		May and June	.189	Rutter 1968
Douglas-fir	Canada	July	.136	McNaughton and Black 1973
Pine	New Jersey	May-October	.117	Rutter 1968
Pine	Arizona	May-October	.129	Thompson 1974
Pine	Oregon	August	.139	Gay 1971
Aspen	Colorado	June-September	.154	Rutter 1968
Brush	Utah	May-November	.065	Rowe and Reiman 1961
Grassland	Colorado	June-September	.079	Brown and Thompson 1965
Grassland	Utah	May-November	.048	Rowe and Reiman 1961

Water Yield Results

A total of five treatments on Workman Creek[3] and one on Castle Creek, have been evaluated to date. These are: (1) North Fork riparian cut of broad-leaved trees; (2) North Fork moist-site cut of Douglas-fir and white fir with conversion to grass; (3) North Fork dry-site cut of merchantable ponderosa pine with conversion to grass; (4) South Fork individual tree selection cut; (5) South Fork clearcut with planting of ponderosa pine (to eventually achieve 40 ft^2 of basal area per acre); and (6) Castle Creek patchcut—one-sixth cleared, remaining five-sixths put in best possible growing conditions.

The removal of a small quantity of deciduous riparian trees on the North Fork, where a stand of white fir and Douglas-fir remained near the stream channel, did not increase water yields. Similarly, a heavy removal of mature and overmature forest vegetation that left a large residual stand on South Fork did not significantly affect water yields.

Table 2 summarizes the results from the four watershed treatments that significantly increased water yields. These data are plotted in figure 2. Increases in water yields were calculated as the differences between before-treatment and after-treatment regressions. The consistency of the data lends credence to this predictive nomograph, but qualifying statements must be added.

This simple graphic model applies only to mixed conifer types of the Southwest, where conditions are comparable to those of the Workman Creek-Castle Creek areas. The most important of these conditions is probably the percent of annual precipitation occurring as streamflow (annual runoff efficiency). This efficiency is an integrated measure of many watershed factors, such as soil-water recharge requirements, degree to which the vegetation occupies the site, and numerous physiographic factors. Establishing this comparability may

[3]*Rich, Lowell R., and Gerald J. Gottfried. Water yields resulting from treatments on the Workman Creek experimental watersheds. (Manuscript in preparation at the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.)*

Table 2.--Water yield increases (inches) expected from watershed treatments, computed from regression equations

Watershed and treatment	Yield increase expected from treated watershed if runoff from control watershed is--						
	1 inch	2 inches	3 inches	4 inches	5 inches	6 inches	7 inches
	Inches						
West Fork of Castle Creek							
17 percent of area in clearcut openings, balance of watershed harvested	0.41	0.50	0.60	0.69	0.78	0.88	0.98
North Fork of Workman Creek							
33 percent of area cleared and planted to grass (moist site)	.92	1.15	1.38	1.61	1.84	2.06	2.29
North Fork of Workman Creek							
73 percent of watershed area cleared and planted to grass (dry site)	1.05	2.09	3.13	4.16	5.20	6.24	
South Fork of Workman Creek							
83 percent of area cleared preparatory to planting	1.39	2.66	3.92	5.19	6.46	7.72	

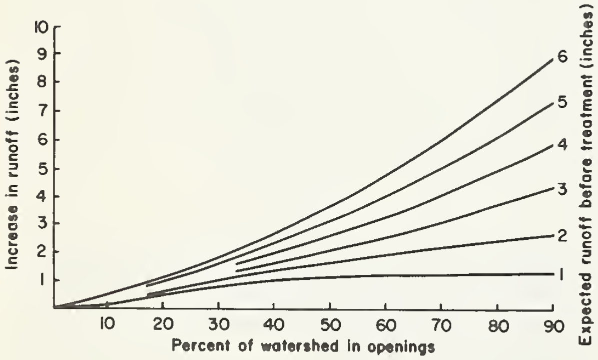

Figure 2.—Potential water yield increases from watershed treatments in pine-fir and mixed conifer vegetation. (Spaces greater than three times the height of the surrounding trees are considered openings.)

not be a serious problem in Arizona's mixed conifer forests, however, because the delineation of the type is itself a measure of many of these conditions. Figure 2 may be used as a predictor in land management planning, subject only to the caution that it is offered as an aid in decisionmaking, not a panacea.

Results presented here are based on clearcutting and patchcutting. Openings in the forest greater than three times the height of the surrounding trees, are effective in redistributing snow and reducing evapotranspiration. In recent years "clearcutting" has become synonymous with vast areas of devastation created in the name of watershed management. Small, irregularly shaped "patchcuts" that promote snow accumulation and reduce soil moisture deficits and evapotranspiration can be esthetically pleasing, improve wildlife habitat by increasing cover diversification, improve herbage production for livestock, and still provide a high quality, sustained yield of timber while increasing streamflow.

Computer simulation of hydrologic results of patchcutting has shown that magnitude of peak flows is not changed significantly, but their timing is altered appreciably. Duration of runoff remains essentially unchanged (Leaf and Brink 1972). Conversely, clearcutting in large, regularly shaped blocks is esthetically displeasing and can drastically alter the seasonal hydrograph. After total clearcutting, the 200-acre mixed conifer watershed at Wagon Wheel Gap produced much greater flood peaks (Bates and Henry 1928). Although the large clearcuts are more easily logged and produce a greater percentage increase in total water yield, the large flood flow is of questionable benefit.

Removal of moist-site forest vegetation—Douglas-fir and white fir—from 80 acres of a 248-acre watershed increased water yields 45 percent. Clearing an additional 100 acres of dry-site forest vegetation—dominantly ponderosa pine—further increased water yields. Compared to original conditions, increases varied from 81 percent at 1-inch yield from the control watershed to 109 percent at 7-inch yield from the control. Clearcutting 83 percent of a 318-acre watershed resulted in water yield increases varying from 91 percent at 1-inch yield from the control watershed to 140 percent at 7 inches from the control. Clearcutting one-sixth of a 900-acre watershed, where the remaining five-sixths of the watershed was placed in the best growing condition possible, increased water yield about 29 percent.

In contrast, annual water yields following the individual tree selection harvest on South Fork of Workman Creek were not significantly changed by the treatment. A substantial amount of timber was removed by this timber harvest and by fire, but the removal was spread over 5 years. Voids in the stand probably filled naturally and quickly, and—also—a comparatively heavy stand of trees remained after the harvest. Even after 46 percent of the basal area of trees on the watershed were removed, 107 ft^2 per acre remained.

A riparian cut of Arizona alder and big-tooth maple adjacent to streams and seeps on North Fork of Workman Creek that removed 0.6 percent of the total basal area of all trees on the 248-acre watershed did not significantly increase water yields.

A second test of forest management on water yields is currently underway, and future multiproduct tests are planned for two additional calibrated watersheds.

Erosion Measurements

Erosion, sediment losses, and the corresponding quality of water depend not only on the type of watershed and the amount and condition of the watershed cover, but also on the point and time of measurement. Sediment losses from a wildfire in South Fork of Workman Creek illustrate these variations (Rich 1962).

The fire was started by lightning on July 6, 1957, and was carried into South Fork of Workman Creek by high winds. Conditions were extremely dry; only 2.97 inches of rain had fallen since March 22. The fire, which crowned in the trees, consumed litter and ground vegetation and killed all but a few large trees along the edge of the 60-acre burn. Immediately after the fire, the area was seeded to grass, and a good stand of grass and New-Mexican locust was established before the end of the summer. Sediment movement following the fire was based on measurements of (1) profiles across random timber sample plots, (2) random cross sections in the lower 3,600 ft of the main stream channel, (3) sediment trapped in the weir ponds, and (4) profile lines across randomly located seeding plots.

The first storm after the fire, on July 16, was one of the heaviest measured in Workman Creek. Total precipitation measured at two gages inside the burn area was 3.50 and 4.05 inches. At the Workman Creek Climatic Station about ¾ mile north of the burn, 3.41 inches of precipitation were recorded between 7 and 11 p.m. Total summer precipitation (June, July, August, and September) was 10.60 inches, only slightly above average.

Profile measurements indicated approximately 1 acre-ft of sediment (an average depth of 0.016 ft) was eroded from the burn. Sediment was deposited immediately below the burn in unburned forest vegetation, in the stream channel, and in the weir pond. Only 818 ft^3 (approximately 2 percent) was deposited in the weir pond. Approximately 39 percent (17,000 ft^3) was deposited in the stream channel between the fire and the weir pond at the lower end of the 318-acre watershed. Most of the remaining sediment was deposited on flat areas just outside the burn.

The amount of sediment trapped in weir ponds from the East Fork of Castle Creek is similar to the prefire value from Workman Creek. Castle Creek vegetation is basically ponderosa pine with mixed conifer vegetation on north-facing slopes. Measuring weirs and ponds were completed during the summer of 1955. Three years later following a year of higher-than-average runoff, 44 yd^3 (1.0 ft^3 per acre per year) were trapped in the East Fork weir pond from a watershed of 1,163 acres. Two years later, 18 yd^3 (0.4 ft^3 per acre per year) were measured in the East Fork pond. In contrast, the adjoining 900-acre West Fork watershed had trapped no sediment in the weir pond during this same pretreatment period (1955-60).

The only sizable amounts of sediment moved from these White Mountain watersheds as a result of a series of thunderstorms in October 1972. During the 2 weeks prior to the major runoff event on October 19 and 20, 7¼ inches of rain had fallen. On October 19, an additional 4 inches fell in a 24-hour continuous storm. Average intensity for this period was about 0.17 inch per hour, with a maximum of 1.15 inches per hour at noon that lasted for a half hour. The peak flows were not much different for the two watersheds (120 $ft^3/s/mi^2$—West

Fork; 125 ft³/s/mi²—East Fork), but the treated West Fork produced 2.5 times more sediment than the control watershed.

On-the-ground observations during and after this storm event seemed to support the conclusion of Copeland (1969) that logging roads are the primary source of erosion. The treated watershed had considerably more sediment accumulation in the channels, from the years immediately following logging. This flood merely flushed the channels. No erosion was detected on the saturated land surfaces by an observer walking across the watersheds during the height of the thunderstorm. Only slight amounts of soil movement were detected from the old, revegetated logging roads.

Roosevelt Reservoir, about 55 miles east of Phoenix, Arizona, began storing water shortly after the dam was completed March 18, 1911. A survey made in 1925 showed a total accumulation of 101,000 acre-ft of sediment, an average annual rate of accumulation of 7,214 acre-ft or 125.2 acre-ft per 100 mi² from the 5,760-mi² watershed above Roosevelt Dam (Eakin 1936).

In 1946, total sediment was 142,450 acre-ft. Over the 36-yr period, this indicates 3,957 acre-ft per year or about 68.7 acre-ft per 100 mi² of drainage area.

Table 3 compares sediment yields from Arizona mixed conifer watersheds with sediment yields from the Salt River as measured in Roosevelt Reservoir and from Fraser Experi-

Table 3.--Sediment yields from selected watersheds in Arizona and Colorado

Watershed	Size	Vegetation	Period	Average annual sediment production	Remarks
				ft³/acre	
Salt River above Roosevelt	5,760 miles	Desert to alpine	1911-25	85.2	
			1911-46	46.8	
Workman Creek					
North Fork	248 acres	Mixed conifer	1939-58	0.4	
			1959	2.3	First year after treatment.
			1960	6.2	Second year after treatment.
			1970	1.4	Year of maximum storm (11.4 inches in 24 hours)
South Fork	318 acres	Mixed conifer	1939-53	0.14	
	60-acre burn		1957	726	Fire destroyed 74 percent of basal area
	318 acres		1957	14	
	318 acres		1958-60	4.4	
Castle Creek					
East Fork	1,163 acres	Pine-fir	1958	1.0	Fully stocked (control watershed)
			1960	0.4	
			Oct. 1972	0.9	
West Fork	900 acres		1958-60	0	Fully stocked
			Oct. 1972	2.4	1/6 clearcut in 1965-66
Fraser, Colorado					
Fool Creek	714 acres	Lodgepole pine spruce-fir	1952	2.2	Logging roads constructed
			1953	1.1	
			1954-55	0	
			1956	1.8	Timber harvest
			1957-58	2.8	
			1959-65	0.5	
Deadhorse	667 acres		1955-65	0.4	Fully stocked, untreated
Lexen	306 acres		1956-65	0.3	Fully stocked, untreated

mental Forest watersheds in Colorado (Leaf 1966). These data indicate that: (1) the mixed conifer type produces very little sediment compared to the integrated total of all vegetative types in the Salt River basin, (2) road construction and timber harvest increase sediment production, and (3) wildfire is a greater sediment-producing agent than man's logging activities.

Discussion and Conclusions

How forest vegetation affects water and sediment yield has been studied by removing forest vegetation. Some extreme treatments have been applied in manipulating the watershed vegetation to determine threshold or extreme values for research purposes.

Water Quantity

Management can change the yields of water products on experimental watersheds. Clearcutting forest vegetation has increased water yields approximately in proportion to the percent of the area clearcut (fig. 3).

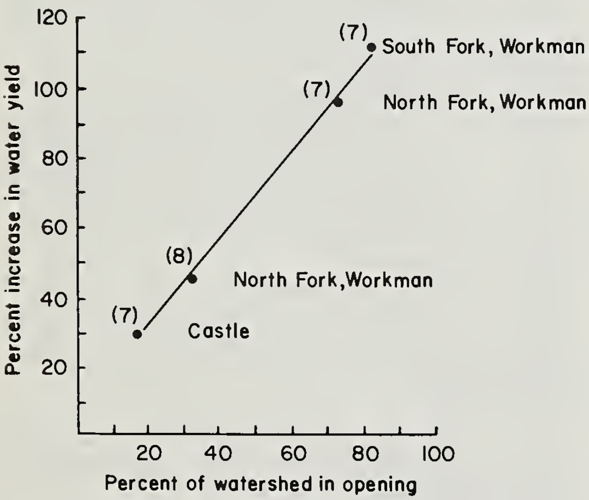

Figure 3.—Water yield increase as a function of the percent of the area in openings.

Most of the yield increase can be accounted for by the reduction in evapotranspiration. Reduced soil-moisture deficit and increased snow accumulation and melt rates in the cut openings are additive factors that contribute to these increases. Water use data from Black Mesa in western Colorado (Brown and Thompson 1965) and evapotranspiration estimates from energy budget data in eastern Arizona (Thompson 1974) both support a 4- to 5-inch reduction in evapotranspiration in the clearcut openings on Castle Creek. Since these openings occupy 153 acres on the 900-acre watershed, a 4- to 5-inch reduction would mean an additional 52 acre-ft or 0.7 area-inch available to streamflow. Before treatment, Castle Creek averaged 2 inches of streamflow annually. Entering figure 2 with 17 percent as the amount in openings, and 2 inches of streamflow, the increase predicted by this chart is also 0.7 inch.

When fitted to the timber stand structure, clearcutting in small patches is compatible with recommended silvicultural methods for mixed conifers (Alexander 1974). These small forest openings also improve wildlife habitat for such species as deer, elk (Reynolds 1966, Wallmo 1969), grouse (Martinka 1972), and turkey.[4]

Water Quality

Sediment quantities vary over time and by measurement point. The annual rate of sedimentation was almost double in Roosevelt Reservoir for the period 1911-25 (Eakin 1936) compared to 1911-46.[5]

Fire and loss of vegetation significantly increase sediment losses (Rich 1962). Location and type of measurements have influenced apparent sediment quantities. Sediment losses as the result of a severe fire on Workman Creek varied from a rate of 0.21 to 1,066 acre-ft per 100 mi^2, depending on where and how measurements were made.

It is possible to treat watersheds without a serious increase in sediment yields. The Workman Creek rain gage recorded the all-time Arizona record for 24-hour precipitation on September 4 and 5, 1970 (U. S. Department of Commerce 1970). The watersheds were under treatment, yet sediment losses were relatively light on North Fork watershed. There was no apparent sediment loss measured at the mouth of the South Fork watershed.

Although it is evident that timber harvesting and the accompanying road construction can increase sediment production, they are insignificant in comparison to nature's destructive

[4]*Scott, Virgil E., and Erwin L. Boeker. Ecology of Merriam's wild turkey on the Fort Apache Indian Reservation. (Unpublished manuscript by Fish & Wildlife Service, U. S. Department of the Interior, on file at the Forestry Hydrology Laboratory, Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.)*

[5]*Salt River Water Users' Association. Chart titled "Combined flow of Salt and Verde Rivers." 1971.*

forces such as fire and thunderstorms. In the mixed conifer type, however, the ability of watersheds to revegetate makes major erosion events very temporary occurrences.

Implications

Although the mixed conifer areas of Arizona make up approximately 0.4 percent of the total land area, they contribute 6 percent of the State's water yield. A maximum of 290,000 acres in the mixed conifer could be treated. (At least 29,000 acres are in wilderness and primitive areas, or other land classifications that restrict logging.) Intensive forest management on this maximum area would significantly increase annual water yield. Intensive management is defined here as a patchcutting scheme with openings three to eight tree heights in width, with one-sixth of the area harvested each cutting cycle (approximately 20 years). After half the 120-year rotation age is reached, half the area will have been logged; one-sixth will be in recently cleared patches, one-sixth in 20-year-old reproduction, and one-sixth in 40-year-old pole stands. Each of these areas would be effective to some degree in reducing evapotranspiration and increasing snow accumulation; their effectiveness decreases with height of the new trees, however.

The total area of "effective" clearings would be at least 30 percent. Average runoff for the mixed conifer type is estimated at 4.7 inches (Forsling 1960). From figure 2, the estimated increase is 1½ area inches, which would increase total annual streamflow in Arizona by 1.8 percent, or about 36,500 acre-ft—12 billion gallons.

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Appendix

Workman Creek

These mixed conifer watersheds, on the Sierra Ancha Experimental Forest about 50 miles north of Globe, were calibrated and ready for treatments by 1954. Elevations vary between 6,590 and 7,700 ft for the bowllike basin that drains to the West. Each of the three watersheds—North Fork 248 acres, Middle Fork 521 acres, and South Fork 318 acres—supports a perennial stream.

Surface soils are of loam to clay loam texture, subsoils vary in texture from clay loams to clay. Infiltration rates are high near the soil surface and diminish with depth to extremely low rates below 12 inches.[6] Soil depth varies from a few inches to more than 15 ft. The watersheds are underlain by quartzite rock that has been intruded by diabase and basalt. Most formations are level. Average annual precipitation is just over 32 inches; streamflow prior to treatment had averaged from 3.19 to 3.42 inches for the three watersheds.

Winter precipitation, October through May, has averaged 66 percent of the annual total.

The forest vegetation on the Workman Creek watersheds is dominantly ponderosa pine, Douglas-fir, white fir, and Gambel oak. Proportions of the most abundant trees on the three watersheds prior to treatment were:

	North Fork	Middle Fork	South Fork
		(Percent)	
Ponderosa pine	52.2	46.4	59.4
White fir	20.1	20.2	25.5
Douglas-fir	4.1	10.1	5.8
Gambel oak	22.2	21.8	8.0
Other	1.4	1.5	1.3

Arizona alder and bigtooth maple are found adjacent to streams and seeps. Arizona walnut and quaking aspen are found sparingly; New-Mexican locust, found as a part of the understory, is often first to occupy the site when released by overstory removal.

North Fork riparian cut.—On the North Fork of Workman Creek watershed, we tested treatments intended to approach maximum water yield. The forest vegetation was converted to grass in four steps. The first step was to cut and poison all broad-leaved trees on wet sites along the stream channel. The Arizona alder and bigtooth maple adjacent to streams, springs, and seeps were cut during August 1953. Stumps were treated to prevent sprouting. The cut included 158 alders varying in diameter from 1 to 33 inches and 946 maples varying from 1 to 11 inches. The total basal area of these trees was approximately 0.6 percent of the total basal area of trees on the 248-acre watershed.

Annual water yields did not increase significantly following the removal of broad-leaved trees. Since riparian trees are deciduous, the streamflow was tested to determine whether their removal affected growing season water yield. The posttreatment years were not significantly different from the pretreatments years. Also, removal of the riparian trees did not change diurnal fluctuations of streamflow.

North Fork moist-site cut.—In the second treatment on North Fork all trees (mainly Douglas-fir and white fir) growing on moist sites (about 80 acres) were removed in fall of 1958 and replaced with perennial grass.

A break in topography between the steeper, moist slopes extending up from the stream channel and the flatter, dry slopes above the moist-site areas delineated the area for clearing in many places. Where topography did not determine the boundary, the area was considered moist-site wherever white fir and

[6]*Barret, Thomas W. Final report, Cooperative Agreemnt No. 16-68, Line Proj. FS-RM-1606, 319 p. 1970. On file at Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.*

Douglas-fir stems 4 inches and larger made up more than 50 percent of the forest stand. Moist-site vegetation was found along both sides of the main stream channel and two contributing forks in the upper reaches of the watershed.

Trees larger than 10 inches were cut and removed to the sawmill. Smaller trees were pushed over with a bulldozer. Unmerchantable material was piled into windrows for burning. Most of the forest litter and debris was also pushed into slash piles, leaving a good seedbed for perennial grasses between the windrows.

Ground between the slash piles was seeded to a mixture of 40 percent slender wheatgrass (*Agropyron trachycaulum* (Link) Malte), 40 percent Kentucky bluegrass (*Poa pratensis* L.) and 20 percent orchardgrass (*Dactylis glomerata* L.) at the rate of 10 pounds per acre. Redtop (*Agrostis alba* L.) was planted along stream channels and seeps at the rate of 10 pounds per acre. Slash was burned in March 1959. In most of the slash piles, material smaller than 6 inches d.b.h. was consumed. Larger material was charred but not completely consumed.

Subsequent streamflow measurements have shown statistically significant water yield increases, and also a significant difference in pre- and posttreatment regression coefficients.

The different regression coefficients for the two periods indicate a fairly consistent yield increase for individual years that averages 45 percent higher than expected without treatment. Increases were smallest during the years of lowest runoff, larger during the years of higher streamflow.

North Fork dry-site cut.—The third treatment on North Fork replaced the merchantable tree area (ponderosa pine) on dry sites with grass. One hundred acres of merchantable ponderosa pine timber were harvested between September 1966 and June 1968. In December 1969 the remaining standing trees and slash accumulations were burned. The area was then seeded to the same grass mixture used for the moist-site area.

Streamflow measurements indicate additional water yield increases, as a result of the dry-site cut alone, varying from 15 percent when yields are 1 inch, to 38 percent at 3.0 inches, and 56 percent when the check watershed yields 7.0 inches. Comparing total yields after both the moist-site and dry-site cut indicates water yield increases varying from 72 percent at 1 inch, to 99 percent at 3.0 inches, and 110 percent when the check watershed yields 7.0 inches.

Covariance analysis for average conditions indicates a 45 percent increase for the moist-site cut, another 34 percent increase for the dry-site cut, and 96 percent increase for the two cuts combined.

South Fork selection harvest.—South Fork of Workman Creek, the other treatable watershed, was first managed for production of high-quality timber to determine the effect of individual-tree-selection harvesting on water yields and sedimentation.

The timber management cut was started in June 1953 and completed in November 1955. The gross volume marked for cutting was 3 million fbm (board ft), and the net volume after allowance for defect was almost exactly 2 million fbm. This harvest removed approximately 46 percent of the merchantable timber (conifers 12 inches and over). Basal area of trees 1 inch and over was reduced 24 percent. Logging damage, access roads, and skid trails reduced basal area by 6 percent.

Stand improvement work completed during 1956 consisted of poisoning undesirable trees with ammate. In small areas of pine infested with dwarf mistletoe, all trees were poisoned. Larger areas of infestation were isolated by poisoning a 60-ft border around the infestation. Gambel oak and New-Mexican locust which overtopped pine reproduction were also poisoned. In addition, where the composition was a mixture of pine and fir, firs were poisoned to favor growth and reproduction of pine. This improvement work reduced the basal area on the watershed by 6 percent. Slash was piled and burned along the main access roads. Roads, skid trails, and landing areas were subsequently seeded to perennial grass.

On July 6, 1957, a wildfire burned 60 acres of the upper southeast portion of the watershed. The fire burned the most level part of the South Fork watershed where stream channels are not well defined and where there is no perennial streamflow. The fire destroyed about 5,400 ft^2 of basal area on the 60 acres, or about 9 percent of the original basal area on the entire watershed. Thus, total basal area was reduced 45 percent by logging, road construction, improvement measures, and fire.

Annual water yields did not increase significantly when compared with yields from the control watershed. Water yields increased 4 or 5 percent 10 out of the 13 years, but this increase was not statistically significant.

South Fork conversion cut.—The second treatment was the transition of the entire South Fork watershed to ponderosa pine with 40 ft^2 basal area per acre. The timber harvest was started in late September 1966 and finished in June 1968. All merchantable timber was removed from the ponderosa pine area. Areas of dominantly white fir and Douglas-fir were cleared. Pine seedlings were planted in these cleared areas and in the burn area. The goal is to achieve a stocking level of 40 ft^2 of basal area per acre, all in ponderosa pine. In the meantime, we are collecting data on the effects of removing forest vegetation on water and sediment yield. In the future, data will be gathered on the effects of reforestation on water and sediment production.

The water yield results from South Fork almost exactly parallel the results from the combined moist- and dry-site cuts on North Fork. Water yield increases, when compared to the control Middle Fork watershed, vary from 185 percent when the control watershed yields 1.0 inch to 209 percent at 3.0 inches and 241 percent at 7.0 inches. Covariance analysis at average conditions indicates an increase of 111 percent, which compares favorably with the 96 percent for the North Fork watershed.

Castle Creek

The study area includes two watersheds, East Fork (1,163 acres) and West Fork (900 acres), in the Apache National Forest about 20 miles south of Alpine, Arizona. They drain into the San Francisco River, a tributary of the Gila. The western boundaries are adjacent to the Black River, a tributary of the Salt. Consequently, these watersheds should be representative of both the Gila and Salt River headwater areas. Elevations vary from 7,835 to 8,580 ft. The topography is relatively flat; slopes average about 12 percent and the watersheds have been described as an easy logging chance. The town of Alpine, at almost exactly the same elevation as Castle Creek, has an average temperature of 43.3°F, with 250 days with a minimum of 32°F or below, and 15 days with a minimum of 0°F or below. Freezing temperatures have been recorded every month of the year.

Castle Creek is predominately ponderosa pine, but is immediately adjacent to the extensive mixed conifer stand in the White Mountains of eastern Arizona. Because of its climatologic and hydrologic similarity to the mixed conifer, and because of its dissimilarity in stand characteristics to much of the ponderosa pine in Arizona, we have considered it in our analyses as mixed conifer.

The watersheds were selected and 120° V-notch weirs were installed in 1955 to measure water yields. A systematic sampling of the two watersheds provided the following average measurements:

	West Fork	East Fork
Size (acres)	900	1,163
Aspect (direction, average of plots)	S43°E	N14°W
Slope (average of all measured points, percent)	12.6	13.8
Forage production (pounds per acre)	78.2	119.8
Litter (pounds per acre)	33,177	31,085
Soil mantle depth (ft)	2.6	2.8
Forest stand volume:		
(fbm per acre)	11,060	10,680
(ft^3 per acre)	2,723	2,139
Basal area (ft^2 of all trees 1 inch and over)	135	122

Precipitation at Castle Creek for the period 1957-73 averaged 26 inches; 54 percent occurred between October 1 and May 31. Maximum annual precipitation (37 inches) fell during water year 1973; the minimum (21 inches) occurred during 1970. The maximum monthly precipitation (11.4 inches) fell in October 1972. Three months during the 17-year period received no precipitation. August, the highest month, received 16 percent of the average annual total, and May, the lowest month, received 2.4 percent. Precipitation in May and June, the low point of the year, averaged only 6.1 percent of the annual total.

The treatment applied to the 900-acre West Fork of Castle Creek was a commercial timber harvest that placed five-sixths of the watershed in the best growing condition possible for the existing forest stand. It removed (1) poor risk and overmature trees, (2) mature trees where necessary to release needed age classes, (3) trees that overtopped or crowded residual crop trees, (4) poorly formed and other poor classes of trees, (5) damaged trees, and (6) all trees infected with dwarf mistletoe.

The forest on one-sixth of the watershed was clearcut in blocks fitted to existing stands of overmature and unneeded tree classes. The clearcut blocks were treated to obtain natural regeneration as a start toward even-aged management. Some planting was necessary to insure full stocking in these blocks.

The objective of the treatment on Castle Creek was to apply an improved type of timber harvest and subsequent management to obtain data useful in both timber and watershed management; data would be intermediate between the high and low possible threshold values obtained at Workman Creek. It was anticipated that water yield increases would be part way between those after the individual-tree-selection harvest (no significant increase), and the treatment where forest vegetation was removed and replaced by grass (a large gain).

Streamflow for the East Fork control watershed averaged 2.9 inches during the 10-year calibration period, and 3.6 inches during the first 7 years of the treatment period. On the West Fork watershed, streamflow averaged 2.0 inches during the pretreatment 10 years and 3.1 inches the first 7 years of the treatment period. Streamflow has varied from almost zero—0.03 inch from West Fork and 0.06 inch from East Fork during the 1955-56 water year—to 10.4 inches from West Fork and 13.8 inches from East Fork during the 1972-73 water year. Winter runoff has always ceased before the summer rains. More than 80 percent of the annual streamflow is yielded during February-April. June-September accounted for an average of only 8 percent of annual streamflow from West Fork and 7 percent from East Fork.

Seven years of data indicate a significant increase in annual water yields from West Fork—from more than 0.35 inch when the control watershed yields 0.5 inch annual runoff to more than 1.55 inches when the control watershed yields 13.0 inches annual runoff.

Willow-Thomas Creek

These experimental watersheds include East Fork of Willow Creek, 490 acres; West Fork of Willow Creek, 290 acres; North Fork of Thomas Creek, 440 acres; and South Fork of Thomas Creek, 545 acres. The elevations vary between 8,600 and 9,200 ft. Precipitation since 1959 has averaged 28.8 inches annually, and has varied from 20 to 43 inches. About 50 percent of the annual precipitation falls during the 8 winter months—October through May—and 50 percent during the 4 summer months—June through September.

The forest vegetation includes eight species. Composition of the forest (trees 7.0 inches in diameter and above) on the Willow Creek watersheds is:

	East Fork	West Fork
	(Percent)	
Engelmann spruce	21.7	24.1
Blue spruce	2.0	.1
Douglas-fir	25.7	19.9
White fir	6.6	7.8
Corkbark fir	2.6	9.0
Ponderosa pine	5.9	4.8
Southwestern white pine	3.3	1.8
Quaking aspen	32.2	32.5

East Willow Creek was a second test of the effects of a practical type of timber management on water and sediment yields. The treatment, completed September 30, 1972, was silviculturally fitted to the existing forest stand on the 490-acre watershed. Some portions of the area were selectively harvested, while other portions were harvested by the overstory removal method, based on a 10-inch-diameter marking guide. Results will be available after 4 or 5 years of posttreatment measurements.

South Thomas Creek will be treated in 1976. The treatment selected will depend on a complete benefit-cost analysis of several alternatives. Each alternative will have a specific management goal, and available data on esthetics, wildlife, water, timber, range forage, and erosion will be considered in the evaluation. Results from this treatment will be used to evaluate the various resource response models that were the source of inputs to the benefit-cost analysis. Where models do not exist, pretreatment and posttreatment data will be used to build simulation models.

Agriculture—CSU, Ft. Collins

Rich, Lowell R., and J. R. Thompson.
1974. Watershed management in Arizona's mixed conifer forests: The status of our knowledge. USDA For. Serv. Res. Pap. RM-130, 15 p. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo. 80521.

Removing mixed conifer forest vegetation has increased water yields approximately in proportion to the percent of the area in cleared openings. Most of the yield increase can be accounted for by the reduction in evapotranspiration. Reduced soil-moisture deficit and increased snow accumulation and melt rates in the cut openings contribute to these increases. When fitted to the timber-stand structure, patchcutting is (1) compatible with recommended mixed conifer silviculture, (2) beneficial to wildlife, and (3) esthetically pleasing. Although mixed conifer areas make up only 0.4 percent of the total land area of Arizona, they contribute 6 percent of the State's water yield. Intensive management of these forest lands could increase annual streamflow 36,500 acre-feet per year—roughly 12 billion gallons of water per year.
Keywords: Water yield improvement, mixed conifer, sediment yield.

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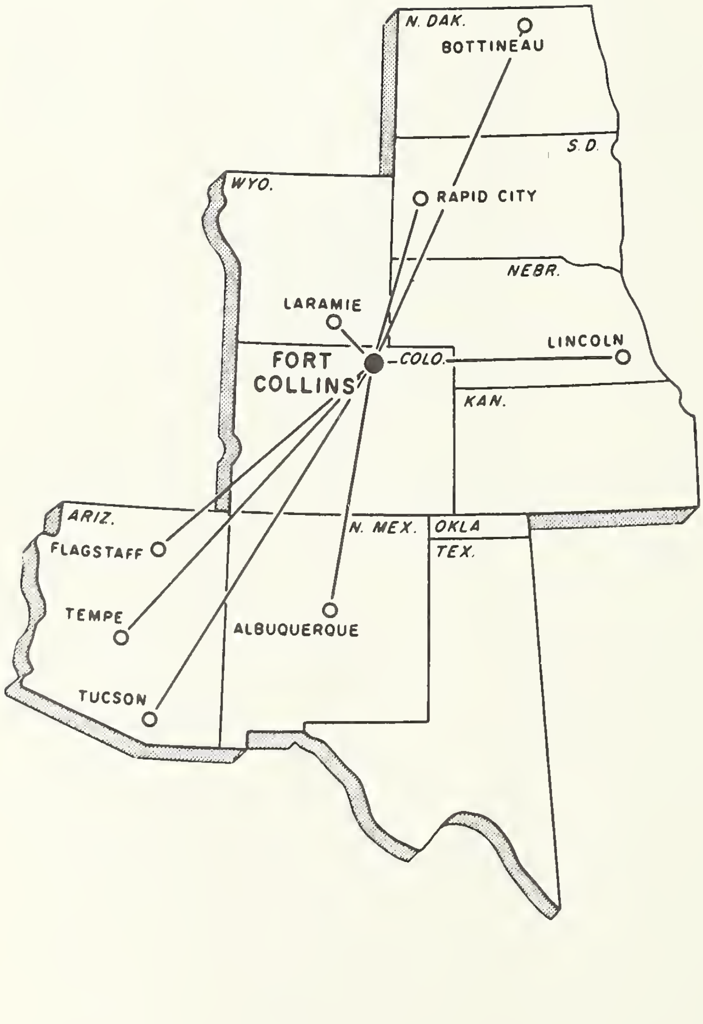
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